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(21)Application number : 08-228781   (71)Applicant : MURATA MFG CO LTD

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(54) SURFACE WAVE DEVICE

(57)Abstract:

PROBLEM TO BE SOLVED: To improve the temperature characteristic and also to increase the electricity-machine coupling coefficient for a surface wave device by setting the normalized thickness of a piezoelectric thin film at the specific value or more.

SOLUTION: A ZnO thin film 12 is formed on the entire surface of a crystal substrate 10, and the IDT 13 and 14 are formed on the film 13 with a space secured between them. The IDT 13 and 14 include a pair of sawtooth electrodes 13a and 13b and 14a and 14b, respectively. When the film 12 is formed on the plate 10, the normalized thickness H/λ of the film 12 is desirably set at ≥ 0.05 (H, thickness of film 12; λ, surface wavelength). The electricity-machine coupling coefficient is usually reduced when the DIT is formed between the no film and the crystal. However, a large electricity-machine coupling coefficient is secured when the DIT 13 and 14 are formed on the film 12 like this example. Furthermore, the electricity-machine coupling coefficient is further increased when a short circuit electrode is inserted into the interface between the plate 10 and the film 12.
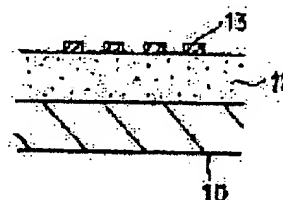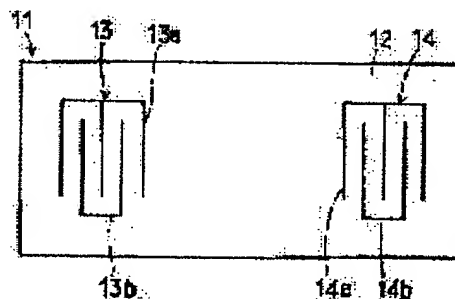
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審査請求　未請求　請求項の数7　ＯＬ　（全 10 頁）

(21)出願番号　特願平8−228781	(71)出願人　000006231 株式会社村田製作所 京都府長岡京市天神二丁目26番10号
(22)出願日　平成8年(1996) 8月29日	(72)発明者　門田　道雄
(31)優先権主張番号　特願平7−225270 (32)優先日　平7(1995) 9月1日 (33)優先権主張国　日本（ＪＰ）	京都府長岡京市天神二丁目26番10号　株式会社村田製作所内 (74)代理人　弁理士　宮▼崎▲　主税　（外1名）

(54)【発明の名称】　弾性表面波装置

(57)【要約】
【課題】　水晶基板を用いて従来より電気機械結合係数が大きいＳＡＷ装置提供する。
【解決手段】　水晶基板１０上にＺｎＯ薄膜１２を形成し、ＺｎＯ薄膜１２上にくし歯電極１３ａ，１３ｂ，１４ａ，１４ｂを形成してなり、ＺｎＯ薄膜１２の規格化膜厚Ｈ／λを０．０５以上としたＳＡＷ装置。

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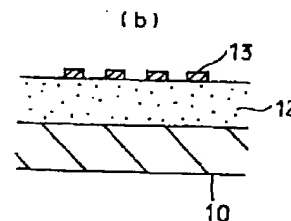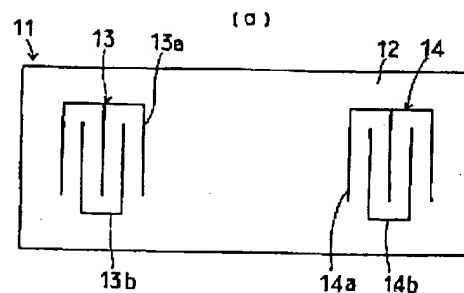
【特許請求の範囲】

【請求項1】 水晶基板と、前記水晶基板上に形成された圧電薄膜と、前記圧電薄膜上に形成されたくし歯電極とを備え、前記圧電薄膜の膜厚をH、表面波の波長をλとしたときに、圧電薄膜の規格化膜厚H／λが0．05以上とされていることを特徴とする、表面波装置。

【請求項2】 前記水晶基板と、前記圧電薄膜との間に形成された短絡電極とをさらに備える、請求項1に記載の表面波装置。

【請求項3】 水晶基板と、前記水晶基板上に形成された圧電薄膜と、前記圧電薄膜に接するように形成されたくし歯電極とを備え、
前記水晶基板として、群遅延時間温度特性TCDがマイナスの値をもつカット角及び伝搬方向の水晶基板が用いられていることを特徴とする、表面波装置。

【請求項4】 前記くし歯電極が、前記圧電薄膜上に形成されている、請求項3に記載の表面波装置。

【請求項5】 前記水晶基板と、前記圧電薄膜との間に形成された短絡電極をさらに備える、請求項4に記載の表面波装置。

【請求項6】 前記圧電薄膜の膜厚をH、表面波の波長をλとしたときに、圧電薄膜の規格化された膜厚H／λが0．03以上である、請求項3～5のいずれかに記載の表面波装置。

【請求項7】 前記圧電薄膜が、ZnO、AlN、Ta₂O₅及びCdSからなる群から選択した一種よりなる圧電薄膜である、請求項1～6のいずれかに記載の表面波装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】 本発明は、水晶基板を用いた表面波装置に関し、特に、水晶基板上に圧電薄膜を積層してなる表面波基板を用いた表面波装置の改良に関する。

【0002】

【従来の技術】 従来より、例えば移動体通信機器の帯域フィルタなどに表面波装置が広く用いられている。表面波（以下、SAW）装置は、圧電体と接するように少なくとも一対のくし歯電極よりなる少なくとも1つのインターデジタルトランスデューサ（以下、IDT）を形成した構造を有する。

【0003】 また、近年、圧電薄膜を用いたSAW装置も種々提案されている。すなわち、ガラス基板や圧電基板上に圧電薄膜を形成してなる表面波基板を用いたSAW装置が提案されている。

【0004】 上記圧電薄膜と、ガラス基板とを用いた構成では、図1（a）、（b）及び図2（a）、（b）に示す4種類の構造が知られている。すなわち、図1（a）に示すSAW装置1では、ガラス基板2上に圧電薄膜としてZnO薄膜3が形成されており、ZnO薄膜

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3上にIDT4が形成されている。他方、図1（b）に示すSAW装置5では、IDT4が、ZnO薄膜3の下面に、すなわちガラス基板2とZnO薄膜3との間の界面に形成されている。

【0005】 また、図2（a）に示すSAW装置6では、ガラス基板2上に、短絡電極7が形成されており、該短絡電極7上にZnO薄膜3が積層されている。IDT4は、このZnO薄膜3上に形成されている。すなわち、SAW装置6は、図1（a）に示したSAW装置1において、ガラス基板2とZnO薄膜3との界面に短絡電極7を挿入した構造に相当する。

【0006】 図2（b）に示すSAW装置8では、短絡電極7がZnO薄膜3上に形成されている。また、IDT4がガラス基板2とZnO薄膜3との間の界面に形成されている。従って、SAW装置8は、図1（b）に示したSAW装置5において、ZnO薄膜3の上面に上記短絡電極7を形成した構造に相当する。

【0007】 上記SAW装置1、5、6、8を、IDT4の形成位置及び短絡電極7の有無のみを異ならせ、他の構成は同一とした場合の電気機械結合係数を図3に示す。図3では、上記4種類のSAW装置1、5、6、8におけるZnO薄膜の規格化された膜厚H／λに対する電気機械結合係数の変化が示されている。なお、本明細書において、HはZnO薄膜の厚みを、λは励振される表面波の波長を示す。また、実線AがSAW装置1の結果を、破線BがSAW装置5の結果を、一点鎖線CがSAW装置6の結果を、二点鎖線DがSAW装置8の結果を示す。

【0008】 図3から明らかなように、H／λを選択することにより、SAW装置5、8において、SAW装置1、6に比べて大きな電気機械結合係数の得られることがわかる。従って、従来、ガラス基板2上にZnO薄膜3を形成した構造では、IDT4をガラス基板2とZnO薄膜3との間の界面に形成した方が大きな電気機械結合係数が得られるとされていた。なお、図3中のセザワ波と記してある波はレイリー波の高次モードの表面波である。

【0009】 また、Jpn. J. Appl. Phys. Vol. 32（1993）2333～2336頁には、LiNbO₃圧電単結晶基板上にZnO薄膜を構成してなる表面波基板を用いた場合のIDTや短絡電極の位置による電気機械結合係数の変化が示されている。これを、図4（a）、（b）及び図5（a）、（b）を参照して説明する。

【0010】 図4（a）は、図1（a）に示したSAW装置1におけるガラス基板2をLiNbO₃圧電単結晶基板に置き換えた構造のSAW装置についてのZnO薄膜の相対的膜厚kh（kは2π／λ、hはZnO薄膜の膜厚）と電気機械結合係数K²との関係を示す。なお、実線＋はLiNbO₃のプラス面上にZnO薄膜を形成

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した場合を、破線－は、ＬｉＮｂＯ₃のマイナス面にＺ
ｎＯ薄膜を形成した場合の特性である。同様に、図4
（b）は、図1（b）に示したＳＡＷ装置5のガラス基
板2をＬｉＮｂＯ₃圧電単結晶基板に置き換えた場合の
電気機械結合係数K²を示す図であり、実線はＬｉＮｂ
Ｏ₃のプラス面上にＺｎＯ薄膜を形成した場合、破線は
マイナス面上にＺｎＯ薄膜を形成した場合の特性を示
す。さらに、図5（a）は、図2（a）に示したＳＡＷ
装置6のガラス基板2を、図5（b）は図2（b）に示
したＳＡＷ装置8のガラス基板2を、それぞれ、ＬｉＮ
ｂＯ₃圧電単結晶基板に置き換えた場合の電気機械結合
係数K²の変化を示す図である。

【0011】図4及び図5から明らかなように、ＬｉＮ
ｂＯ₃圧電単結晶基板上に圧電薄膜としてＺｎＯ薄膜を
形成した構造においても、図4（b）及び図5（b）か
ら明らかなように、ＩＤＴを圧電単結晶基板とＺｎＯ薄
膜との間の界面に形成した方が、大きな電気機械結合係
数K²を実現し得ることがわかる。

【0012】すなわち、従来、ガラス基板や圧電基板上
にＺｎＯ薄膜を形成した表面波基板を用いる場合、大き
な電気機械結合係数を得るにはＩＤＴを圧電薄膜と基板
との間に形成すべきと考えられていた。

【0013】他方、用途によっては、電気機械結合係数
が大きいだけでなく、温度特性が良好である、すなわち
温度変化による特性の変化が小さい表面波基板が求めら
れており、温度特性が良好な基板材料としては水晶が知
られている。しかしながら、水晶基板は電気機械結合係
数が比較的小さいという問題があった。

【0014】前述したように、水晶基板は良好な温度特
性を有する。例えば、回転Ｙカット水晶基板では、図1
0に示すように、オイラー角と、ＴＣＤ及び伝搬損失と
の間に図示のような関係のあることが知られている。こ
こで、ＴＣＤとは、遅延時間の温度による変化率（単位
はｐｐｍ／℃）を示す。

【0015】なお、図10において、実線Aは、回転Ｙ
カット水晶基板上で漏洩弾性表面波を励振した場合のＴ
ＣＤを、実線Bは伝搬損失を、破線Cはレイリー表面波
のＴＣＤを示す。但し、レイリー波の伝搬損失はゼロで
ある。

【0016】図10に示すＴＣＤ及び伝搬損失特性が知
られているため、従来、図10に示すオイラー角が13
0度近辺の回転Ｙカット水晶基板が用いられていた。す
なわち、ＴＣＤが0付近のカット角の水晶基板が用いら
れ、該水晶基板上にＩＤＴを形成してなるＳＡＷ装置
が、温度特性の良好なＳＡＷ装置として用いられてい
た。

【0017】しかしながら、上記のように構成された水
晶基板を用いたＳＡＷ装置においても、やはり、電気機
械結合係数が小さく、従って、例えばＳＡＷフィルタを
構成した場合には、低挿入損失あるいは広帯域のフィル

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タ特性を得ることが困難であった。

【0018】

【発明が解決しようとする課題】本発明の目的は、水晶
基板及び圧電薄膜を積層してなる表面波板を用いたＳ
ＡＷ装置において、電気機械結合係数をさらに高め得る
構造を備えたものを提供することにある。

【0019】また、本発明の他の目的は、温度特性が良
好であり、かつ電気機械結合係数がより一層大きなＳＡ
Ｗ装置を提供することにある。

【0020】

【課題を解決するための手段】本発明は、上記課題を達
成するためになされたものであり、本願の第1の発明の
広い局面によれば、水晶基板と、前記水晶基板上に形成
された圧電薄膜と、前記圧電薄膜上に形成されたくし歯
電極とを備え、圧電薄膜の膜厚をH、表面波の波長をλ
としたときに、圧電薄膜の規格化膜厚H／λが0．05
以上とされていることを特徴とする、表面波装置が提供
される。

【0021】本願の第1の発明にかかる表面波装置で
は、上記のように水晶基板上に圧電薄膜が形成されてお
り、くし歯電極は該圧電薄膜上に形成されている。すな
わち、従来、非圧電基板あるいは圧電基板と圧電薄膜と
を積層してなる表面波基板を用いる場合、ＩＤＴやくし
歯電極は基板と圧電薄膜との間に形成すべきであり、そ
の方が電気機械結合係数を大きくし得ると考えられてい
た。しかしながら、本願発明者は、圧電基板である水晶
基板の場合には、水晶基板上に圧電薄膜を形成し、圧電
薄膜上にくし歯電極を形成した方が、電気機械結合係数
を高め得ることを見出し、さらに、その場合の圧電薄膜
を上記特定の厚みとすれば、より一層電気機械結合係数
を高め得ることを見出し、本願の第1発明をなすに至っ
た。

【0022】上記表面波装置おいては、好ましくは、水
晶基板と圧電薄膜との間に形成された短絡電極がさらに
備えられる。本願の第2の発明の広い局面によれば、水
晶基板と、前記水晶基板上に形成された圧電薄膜と、前
記圧電薄膜に接するように形成されたくし歯電極とを備
え、前記水晶基板として、遅延時間温度特性ＴＣＤがマ
イナスの値をもつカット角及び伝搬方向の水晶基板が用
いられていることを特徴とする、表面波装置が提供され
る。

【0023】第2の発明では、後述の実施形態の説明か
ら明らかなように、水晶基板としては、遅延時間温度特
性ＴＣＤがマイナスの値を持つカット角及び伝搬方向の
水晶基板が用いられ、他方、圧電薄膜が水晶基板上に積
層されている。圧電薄膜は、通常、遅延時間温度特性Ｔ
ＣＤがプラスの値を有する。従って、本発明の上記表面
波装置では、遅延時間温度特性ＴＣＤが、水晶基板と圧
電薄膜とにより相殺されるため、良好な温度特性が実現
される。

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【0024】他方、後述するように、遅延時間温度特性TCDがマイナスの値を持つカット角及び伝搬方向の水晶基板は、遅延時間温度特性TCDがゼロに近いカット角及び伝搬方向の水晶基板に比べて、大きな電気機械結合係数を有する。よって、第2の発明によれば、温度特性が良好であり、かつより大きな電気機械結合係数を有する表面波装置を提供することができる。

【0025】第2の発明の別の特定的な局面によれば、上記くし歯電極は、圧電薄膜上に形成され、従って第1の発明の場合と同様に、より一層大きな電気機械結合係数を実現することができる。

【0026】さらに、第2の発明の別の特定的な局面によれば、水晶基板と、圧電薄膜との間に形成された短絡電極がさらに備えられ、それによって電気機械結合係数が高められる。

【0027】また、第2の発明のさらに別の局面によれば、圧電薄膜の膜厚H、表面波の波長λとしたときに、圧電薄膜の規格化された膜厚H／λが0.03以上とされ、それによって電気機械結合係数がより一層高められる。

【0028】また、本願の第1、第2発明では、上記圧電薄膜は、ZnO、AlN、Ta₂O₅及びCdSからなる群から選択した一種により構成され得る。もっとも、他の圧電薄膜を用いてもよい。上述した材料からなる圧電薄膜は、遅延時間温度特性TCDはプラスの値を有する。従って、本願の第2の発明では、圧電薄膜を上記材料から構成することにより、前述したように温度特性が良好なSAW装置を構成することができる。

【0029】本願の第1、第2の発明にかかるSAW装置は、SAWフィルタ、SAW共振子、SAW遅延線など種々のSAWデバイスに適用し得る。

【0030】
【発明の実施の形態】以下、図面を参照しつつ本発明の前提となる技術を参考例1、2として先ず説明する。

【0031】参考例1
まず、76.2mm径×0.5mmの寸法を有するSTカットX方向伝搬水晶基板を用いて、下記の3種類のSAW装置を作製した。

【0032】SAW装置11…上記水晶基板上にZnO薄膜を全面に形成し、その上に所定距離を隔てて2個のIDTを形成し、SAWフィルタを作製した。すなわち、図9（a）に示すように、圧電薄膜12上において、所定距離を隔ててIDT13，14を形成した。IDT13，14は、それぞれ、一対のくし歯電極13a，13b及び14a，14bを有する。また、このSAW装置11では、図9（b）に示すように、上記水晶基板10上にZnO薄膜12が形成されている。

【0033】SAW装置12…SAW装置11とは異なり、水晶基板とZnO薄膜との間にIDTを形成したことを除いては、SAW装置1と同様にしてSAW装置2

を形成した。

【0034】SAW装置13…SAW装置11において、ZnO薄膜と水晶基板との間に界面の全面にAlよりなる短絡電極を形成し、その他はSAW装置11と同様とした。

【0035】上記SAW装置11〜13において、ZnO薄膜の厚みを種々変更し、ZnO薄膜の厚みと電気機械結合係数との関係を測定した。結果を図6に示す。図6において、破線D、実線E及び一点鎖線Fが、それぞれ、SAW装置11，12，13の結果を示す。なお、図6の横軸は、ZnO薄膜の規格化された膜厚H／λを示す。

【0036】図6から明らかなように、ZnO薄膜の膜厚を調整することにより、SAW装置13において最も大きな電気機械結合係数が得られ、次に、SAW装置11において大きな電気機械結合係数が得られ、SAW装置12ではZnO薄膜を形成することにより逆に電気機械結合係数が小さくなることがわかる。すなわち、図6に示す結果は、STカットX方向伝搬水晶基板では、ZnOの形成されていない水晶に比べ、IDTをZnO膜と水晶の間に形成すると電気機械結合係数が小さくなり、一方IDTをZnO薄膜の上に形成した場合に、大きな電気機械結合係数の得られることを示し、より好ましくは、短絡電極をさらに水晶基板とZnO薄膜との間の界面に挿入することにより、より大きな電気機械結合係数の得られることを示している。

【0037】参考例2
76.2mm径×0.5mmの寸法の165°回転Y板X方向伝搬（オイラー角では0°，75°，0°）の水晶基板を用い、下記のSAW装置14〜16を作製した。

【0038】SAW装置14…基板材料を上記回転Y板X方向伝搬水晶基板としたしことを除いては前述した参考例1のSAW装置11と同様に構成した。
SAW装置15…水晶基板として、上記回転Y板X方向伝搬水晶基板を用いたことを除いては参考例1で作製したSAW装置12と同様に構成した。

【0039】SAW装置16…上記回転Y板X方向伝搬水晶基板を用いたことを除いては、参考例1で作製したSAW装置13と同様にしてSAW装置16を構成した。
上記SAW装置14〜16において、ZnO薄膜の膜厚を種々異ならせ、電気機械結合係数を測定した。結果を図7に示す。

【0040】図7において、破線GはSAW装置14の特性を、実線HはSAW装置15の結果を、一点鎖線IはSAW装置16の結果を示す。図7から明らかなように、回転Y板X方向伝搬水晶基板を用いた場合においても、参考例1の場合と同様に、IDT、すなわち、くし歯電極をZnO薄膜と水晶基板との間に形成するより

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も、ＺｎＯ薄膜上に形成した場合の方が大きな電気機械結合係数の得られることがわかる。また、一点鎖線Ｉ及び破線Ｇの特性を比較すれば明らかなように、さらに水晶基板とＺｎＯ薄膜との間に短絡電極を形成することにより、より一層大きな電気機械結合係数の得られることがわかる。

【００４１】上述した参考例１及び２の結果から、カット角が異なる水晶基板を用いた場合であっても、水晶基板上にＺｎＯ薄膜を形成してなる表面波基板を用いる場合には、くし歯電極をＺｎＯ薄膜上に形成することにより大きな電気機械結合係数の得られることがわかる。上記参考例１，２を前提として、さらに電気機械結合係数を高め得る、本発明の実験例につき説明する。

【００４２】実験例１
先ず、７６．２ｍｍ径×０．５ｍｍの寸法を有する１１５°回転Ｙ板からなる水晶基板を用いた。このカット角の水晶基板は、漏洩弾性表面波において最も大きな電気機械結合係数を得られることが知られている基板材料の一つである。また、漏洩弾性表面波の伝搬方向はＸ方向である。

【００４３】上記１１５°回転Ｙ板Ｘ方向伝搬水晶基板を用い、下記の漏洩弾性表面波を用いたＳＡＷ装置１７〜１９を作製した。
ＳＡＷ装置１７…上記水晶基板を用いたことを除いては、ＳＡＷ装置１１と同様にして構成した。

【００４４】ＳＡＷ装置１８…上記水晶基板を用いたことを除いては、ＳＡＷ装置１２と同様にしてＳＡＷ装置１８を作製した。
ＳＡＷ装置１９…上記特定の水晶基板を用いたことを除いては、ＳＡＷ装置１３と同様にしてＳＡＷ装置１９を作製した。

【００４５】上記ＳＡＷ装置１７〜１９のＺｎＯ薄膜の厚みを種々異ならせ、その電気機械結合係数を測定した。結果を図８に示す。図８において、破線ＪはＳＡＷ装置１７の結果を、実線ＫはＳＡＷ装置１８についての結果を、一点鎖線ＬはＳＡＷ装置１９についての実験結果を示す。

【００４６】また、図８に示した特性において、励振された表面波が漏洩弾性表面波である場合と、通常のレイリー波である場合との区別を図８に示した。すなわち、図８から明らかなように、ＺｎＯ薄膜の規格化された膜厚がＨ／λ＝０．１４未満（二点鎖線Ｍで示す位置）では、減衰を伴う漏洩弾性表面波が励振され、伝搬を用いるトランスバーサル型等のＳＡＷ装置には使用することができないことがわかった。但し、伝搬を必要としないＳＡＷ素子には使用できる可能性がある。従って、ＺｎＯ薄膜の規格化された膜厚を０．１４以上とすることにより、減衰の伴わない電気機械結合係数の大きなＳＡＷ装置の得られることがわかる。

【００４７】また、図８から明らかなように、水晶基板

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とＺｎＯ薄膜との間にくし歯電極を形成したＳＡＷ装置１８では、漏洩弾性表面波を効果的に励振し得ないことがわかる。これに対して、ＩＤＴ、すなわちくし歯電極をＺｎＯ薄膜上に形成してなるＳＡＷ装置１７，１９では、上記Ｈ／λを０．１４以上とすることにより、電気機械結合係数が大きく、かつ減衰のない漏洩弾性表面波を利用したＳＡＷ装置を提供し得ることがわかる。漏洩弾性表面波の場合、図１０Ｂに示したように、基板のカット角により減衰を示す伝搬定数が異なり、ここで示した１１５°回転Ｙ板Ｘ伝搬では、０．２ｄＢ／λの減衰があるが、カット角によっては、減衰がゼロのところ（例えば、１０５°回転Ｙ板や３０°回転Ｙ板のＸ伝搬）がある。このようなカット角では、ＺｎＯ膜厚Ｈ／λが０．０５より大きいところで減衰が伴わず、大きい電気機械結合係数が得られる。

【００４８】なお、図６〜図８に示した結果を比較すれば明らかなように、使用する水晶基のカット角と使用する表面波を励振し得るＺｎＯ薄膜の規格化された膜厚Ｈ／λが異なることがわかり、前述したＳＴカットＸ方向伝搬水晶基板、及び１６５°回転Ｙ板Ｘ方向伝搬水晶基板のようにレイリー波表面波の場合、Ｈ／λを０．０５以上とすればよいことが、さらに漏洩弾性表面波の場合には、１１５°回転Ｙ板Ｘ伝搬水晶基板ではＨ／λが０．１４以上、１０５°回転Ｙ板Ｘ伝搬水晶基板ではＨ／λが０．０５以上とすればよい。従って、水晶基板上にＺｎＯ薄膜を形成する場合、ＺｎＯ薄膜の規格化された膜厚Ｈ／λは０．０５以上とすることが望ましい。

【００４９】上記のように、使用した水晶基板として、オイラー角の異なる回転Ｙ板を種々用いたため、オイラー角が異なる水晶基板を用いた上記ＳＡＷ装置を多数種類作成した。このようにして得たＳＡＷ装置の上記オイラー角と電気機械結合係数Ｋ²との関係を図１６（ａ）に○印を付して示す。

【００５０】なお、図１６（ａ）の実線Ｎは漏洩表面波の、破線Ｐはレイリー波の場合の回転Ｙ板Ｘ伝搬の水晶基板自体の電気機械結合係数を示す。図中○印と●印は、それぞれ、水晶の上にＺｎＯ膜を形成し、さらにその上にＩＤＴを形成した構造におけるレイリー波と漏洩弾性表面波の電気機械結合係数の自乗値Ｋ²を示している。一方△印と▲印は、それぞれ、その構造にさらにＺｎＯと水晶との境界に短絡電極を設けた場合のレイリー波と漏洩弾性表面波の電気機械結合係数の自乗値Ｋ²を示している。このようにＫ²は、カット角により、多少異なる。また、図１６（ｂ）は、図１０と同じ図であるが、図１６（ａ）との比較のために図１６（ａ）の直下に再度図示しているものである。

【００５１】実験例２
図１０を参照して説明したように、従来、水晶基板を用いたＳＡＷ装置を構成する場合、温度特性を良くするためには、ＴＣＤがゼロの近辺のカット角を有する水晶基

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板を用いていたが、この場合充分大きな電気機械結合係数を得ることができなかった。本願発明者は、図10に示すオイラー角と、TCDとの関係において、TCDがマイナスである水晶基板と、ZnO薄膜とを組み合わせれば、良好なTCD及び大きな電気機械結合係数を得られることを見出した。

【0052】なお、水晶基板のカット角及び伝搬方向と、TCDとの関係は、いずれの水晶基板においても、TCDがマイナスの領域は存在する。これを、図11〜図14を参照して説明する。

【0053】図11は、STカット水晶基板における伝搬方向のX軸からの角度θとTCDとの関係を示し、図12はXカット水晶基板の伝搬方向のY軸からの角度θとTCDとの関係を、図13はYカット水晶基板の伝搬方向のX軸からの角度θとTCDとの関係を、図14はZカット水晶基板の伝搬方向のX軸からの角度θとTCDとの関係を示す。図11〜図14から明らかなように、これらの水晶基板においても、伝搬方向角θを変更することにより、TCDがマイナスとなる領域が存在することがわかる。

【0054】本願の第2の発明は、上記のようなTCDがマイナスの値を示すカット角あるいは伝搬方向の水晶基板を、TCDがプラスの値を示す圧電薄膜とを組み合わせることにより、良好なTCDと大きな電気機械結合係数とを実現するものである。これを、回転Y板からなる水晶基板を例にとり、図15を参照して説明する。

【0055】まず、水晶基板として、76.2mm径×0.5mmの寸法の基板を用意した。なお、この水晶基板としては、165°回転Y板X伝搬とSTカット35°伝搬の2種類を用意した。

【0056】上記水晶基板上にZnO膜をH/λ=0〜0.5までの膜厚で成膜し、さらにその上に上記伝搬方向に一致するようにIDTを形成した。そのSAWは特性の遅延時間の温度特性（温度15，25，35℃の3点）を測定した。その結果を図15に示す。165°回転Y板X伝搬では、H/λ=0.35近傍で、STカット35°伝搬ではZnO膜厚H/λ=0.16近傍でTCD=0になるのがわかる。また、この膜厚での電気機械結合係数は前述のように大きい値を示す。すなわち、165°回転Y板X伝搬の場合には、従来、電気機械結合係数K²が0.2％、TCD=−30ppm/℃であったものが、水晶基板にH/λ=0.35のZnO膜とIDTを形成することにより、従来の5倍のK²=1.04％とTCD=0ppm/℃が得られた。また、ZnO膜と水晶基板との間に短絡電極を設けることにより、TCD=0ppm/℃となり、K²はさらに大きい1.35％が得られる。

【0057】一方、STカット35°伝搬の場合にも、従来、K²=0.14％、TCD=−20ppm/℃であったのが、水晶基板上にH/λ=0.16のZnO膜

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とIDTを形成することにより、K²は4.8倍のK²=0.77％とTCD=0ppm/℃が得られる。また、ZnO膜と水晶基板との間に短絡電極を設けると、さらにK²=0.89％とTCD=0ppm/℃が得られる。

【0058】従って、本実験例から明らかなように、水晶基板として、電気機械結合係数が大きなオイラー角の水晶基板を用い、その場合にTCDがマイナスの値を有していたとしても、ZnO薄膜として水晶基板のTCDのマイナスの値を相殺し得るプラスのTCDを示すZnO薄膜を形成し、その上にIDTを形成することにより、非常に大きな電気機械結合係数及び良好な温度特性を有するSAW装置を構成し得ることがわかる。

【0059】上記説明は、2種類の基板について説明したが、回転Y板や、図11〜図14に示した他のカット角の水晶基板を用いた場合においても、同様に、TCDがマイナスであっても、電気機械結合係数が大きなオイラー角の水晶基板を用いることにより、電気機械結合係数が大きくかつ温度特性が良好な表面波装置を構成し得ることがわかる。すなわち、図10に示したように、回転Y板X伝搬におけるレイリー波では、オイラー角（0，0，0）〜（0，135，0）の範囲、漏洩表面波ではオイラー角（0，0，0）〜（0，20，0），（0，45，0）〜（0，65，0），（0，135，0）〜（0，180，0）の範囲がTCDがマイナスの範囲である。図11に示したように、STカット水晶基板を用いた場合には、オイラー角（0，132.75±5，0）から（0，132.75±5，50）の間、及び（0，132.75±5，130）から（0，132.75±5，180）の間で、TCDがマイナスの範囲にある。

【0060】また、図12から明らかなように、回転Xカット水晶基板では、オイラー角が（90，90，0）〜（90，90，35）の範囲及び（90，90，145）〜（90，90，180）の間でTCDがマイナスとなっている。

【0061】同様に、図13に示されているように、回転Yカット水晶基板では、オイラー角が（0，90，0）から（0，90，35）の間、及び（0，90，145）〜（0，90，180）の間でTCDがマイナスとなっている。また、図14から明らかなように、Zカット水晶基板では、オイラー角（0，0，φ）のφが0，60，120及び180以外の伝搬方向の場合にTCDの値がマイナスの値となっている。

【0062】従って、上述した範囲で各水晶基板では、TCDがマイナスの値を示すが、その範囲の中でも電気機械結合係数の大きいカット角を選択し、TCDのマイナスの値を相殺するように、プラスのTCD値を有するZnO薄膜を各水晶基板の上面に形成し、さらにIDTを形成することにより、上記と同様に電気機械結合係数

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が大きくかつ温度特性が良好な表面波装置を構成することができる。

【0063】また、水晶基板のような単結晶の材料を用いた場合には、そのカット角の異方性により、IDTからIDTに向かう位相速度ベクトルの方向と実際のエネルギーの伝搬方向が一致しなくなることがあり、この現象をパワーフローといい、このとき生じる角度をパワーフロー角という。このパワーフローを考慮した場合、パワーフロー角が0であり、同時に、TCDがマイナスの値を示すような角が0であるような水晶基板のカット角が好ましい。この好ましいカット角は、オイラー角（0、25、0）～（0、105、0）の間、（0、0、15）～（0、45、35）の間、（0、10、60）～（0、20、70）の間、（0、90、30）～（0、180、45）の間、（0、0、85）～（0、0、90）の間、（90、90、25）～（90、90、31）の間、（0、90、-3）～（0、90、3）の間であり、この場合TCDがマイナスでありかつパワーフロー角が0である。

【0064】従って、上述した範囲で各水晶基板上にZnO薄膜を形成し、さらにIDTを形成することにより、電気機械結合係数が大きくかつ温度特性が良好で伝搬方向に偏りのない表面波装置を構成することができる。

【0065】なお、上記実験例では圧電薄膜としてZnO薄膜を形成した場合を説明したが、ZnO薄膜のほか、AlN、Ta_2O_5、CdSなどのプラスのTCD値を有する適宜の圧電薄膜を用いてもよい。

【0066】さらに、水晶基板については、プラス面及びマイナス面の何れを用いてもよいことを指摘しておく。

【0067】

【発明の効果】以上のように、本願の第1の発明では、水晶基板上に形成された圧電薄膜上にくし歯電極が形成されており、圧電薄膜の規格化膜厚H/λを0.05以上としているため、大きな電気機械結合係数の得られる表面波装置を提供することができる。すなわち、従来、大きな電気機械結合係数を得られるとされていた水晶基板と圧電薄膜との間にくし歯電極を形成した構造に比べて、電気機械結合係数を飛躍的に高めることが可能となる。

【0068】また、本願の第2の発明によれば、水晶基板としてTCDがマイナスの値をもつカット角及び伝搬方向の水晶基板が用いられ、該水晶基板上に圧電薄膜が形成されている。従って、圧電薄膜が通常プラスのTCD値を有するため、水晶基板のTCD値が圧電薄膜のTCD値により相殺され、温度特性の良好な表面波装置を得ることができる。よって、TCD値がマイナスであっても、電気機械結合係数の大きいカット角及び伝搬方向の水晶基板を用いることにより、従来実現することがで

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きなかった、温度特性が良好であり、しかも大きな電気機械結合係数を有する表面波装置を提供することが可能となる。

【図面の簡単な説明】

【図1】（a）及び（b）は、それぞれ、従来の表面波装置におけるガラス基板、圧電薄膜及びIDTの積層構造を示す各断面図。

【図2】（a）及び（b）は、それぞれ、従来のSAW装置におけるガラス基板、短絡電極、圧電薄膜及びIDTの積層構造を説明するための各断面図。

【図3】図1及び図2に示したSAW装置における圧電薄膜の規格化された膜厚と、電気機械結合係数との関係を示す図。

【図4】（a）及び（b）は、それぞれ、従来のSAW装置において、$LiNbO_3$基板上に圧電薄膜及びIDTを形成した構造及び$LiNbO_3$基板上にIDT及び圧電薄膜をこの順に積層した構造における、ZnO薄膜の規格化された膜厚と電気機械結合係数との関係を示す図。

【図5】（a）及び（b）は、それぞれ、$LiNbO_3$基板上にZnO薄膜を形成してなる表面波基板においてIDT及び短絡電極を異なる位置に形成した場合のZnO薄膜の規格化された膜厚と電気機械結合係数との関係を示す図。

【図6】STカット水晶基板上に圧電薄膜とくし歯電極とを形成した3種類の表面波装置のZnO薄膜の規格化された膜厚と電気機械結合係数との関係を示す図。

【図7】165°回転Y板X方向伝搬水晶基板上にZnO薄膜及びくし歯電極を形成した3種類の構造の表面波装置のZnO薄膜の規格化された膜厚と電気機械結合係数との関係を示す図。

【図8】115°回転Y板からなる水晶基板上にZnO薄膜及びくし歯電極を種々の形態に構成した表面波装置におけるZnO薄膜の規格化された膜厚と電気機械結合係数との関係を示す図。

【図9】（a）及び（b）は、参考例及び本発明の一実施形態として構成されるSAW装置の模式的平面図及びくし歯電極が形成されている部分の部分切欠断面図。

【図10】回転Y板水晶基板におけるオイラー角とTCD及び伝搬損失との関係を示す図。

【図11】STカット水晶基板における伝搬方向とTCDとの関係を示す図。

【図12】Xカット水晶基板の伝搬方向とTCDとの関係を示す図。

【図13】Yカット水晶基板の伝搬方向とTCDとの関係を示す図。

【図14】Zカット水晶基板の伝搬方向とTCDとの関係を示す図。

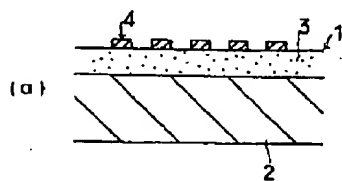【図15】165°回転Y板X伝搬とSTカット35°伝搬水晶基板を用いた場合のZnO膜厚とTCDとの関

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係を示す図。

【図16】（a）及び（b）は、それぞれ、本願の第2
の発明の実施形態における回転Y板水晶基板のオイラー
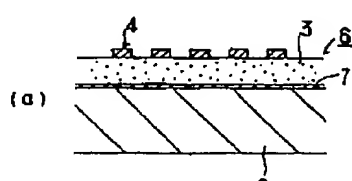角と電気機械結合係数との関係を示す図、並びにオイラ
一角とTCD及び伝搬損失との関係を示す図。

【符号の説明】

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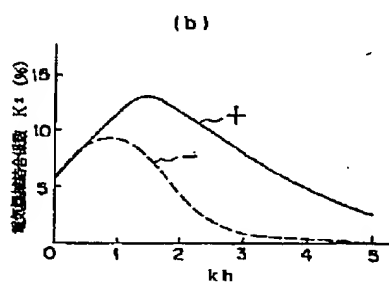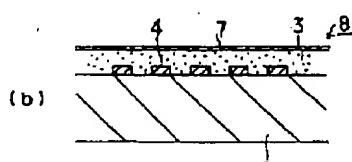10…水晶基板
11…SAW装置
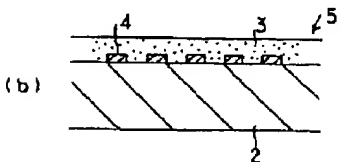12…ZnO薄膜
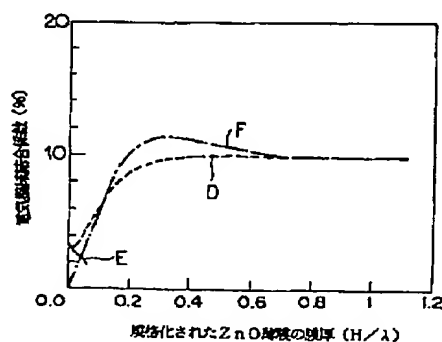13，14…IDT
13a，13b，14a，14b…くし歯電極

【図1】

(a)

(b)

【図2】

(a)

(b)

【図4】

(a)

(b)

【図3】

【図6】

−8−

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【図5】

（a）

（b）

【図7】

【図14】

【図9】

（a）

（b）

【図8】

【図10】

【図11】

－9－
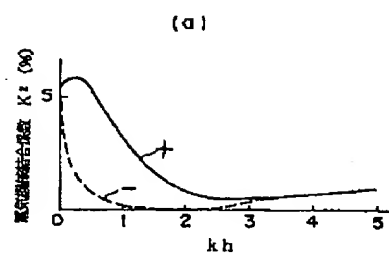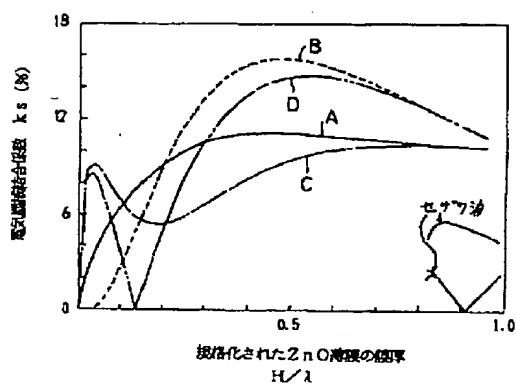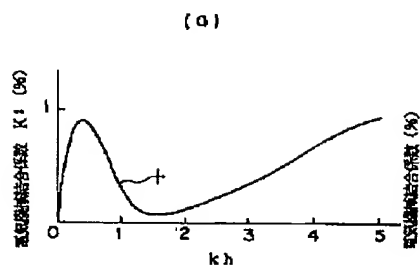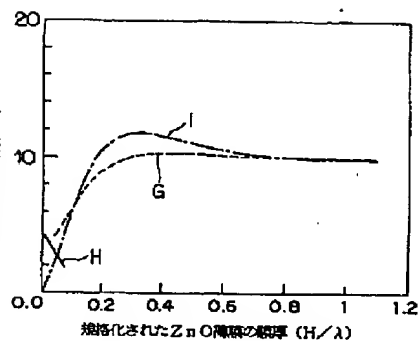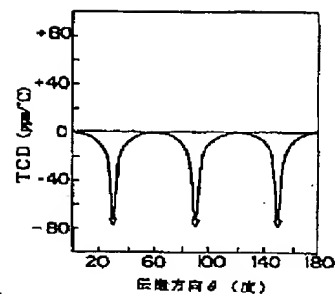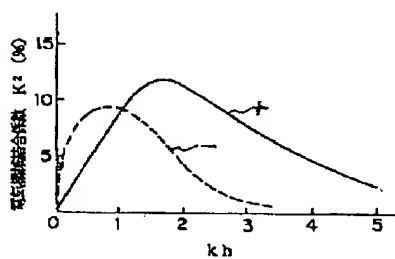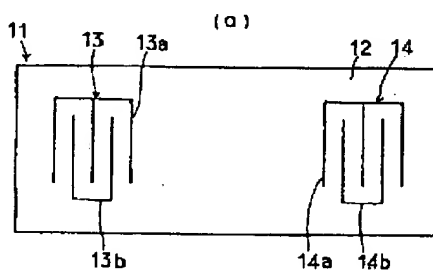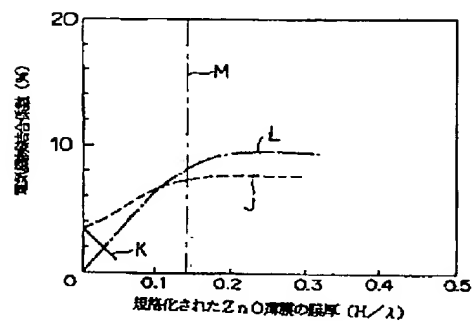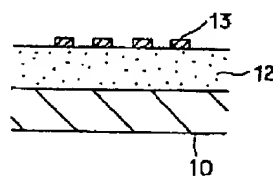
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【図12】

【図13】

【図15】

【図16】

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Bibliography

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(12) [Kind of official gazette] Open patent official report (A)
(11) [Publication No.] JP, 9-130192, A
(43) [Date of Publication] May 16, Heisei 9 (1997)
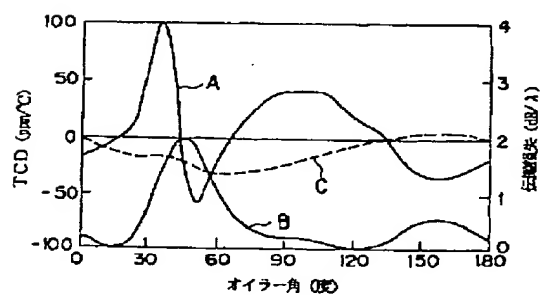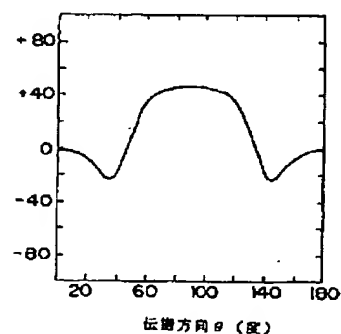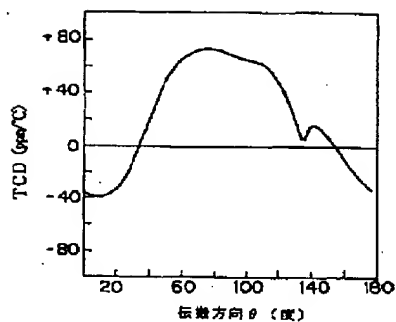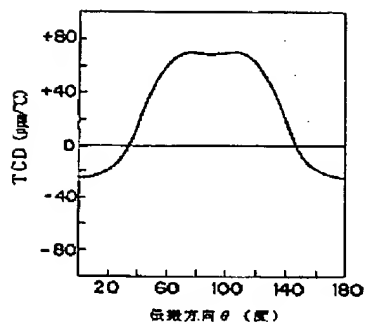(54) [Title of the Invention] Surface wave equipment
(51) [International Patent Classification (6th Edition)]
H03H 9/145
[FI]
H03H 9/145 C 7259-5J
[Request for Examination] Un-asking.
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7-225270
(32) [Priority date] Taira 7 (1995) September 1
(33) [Country Declaring Priority] Japan (JP)
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[Name] Miyazaki The main tax (besides one person)

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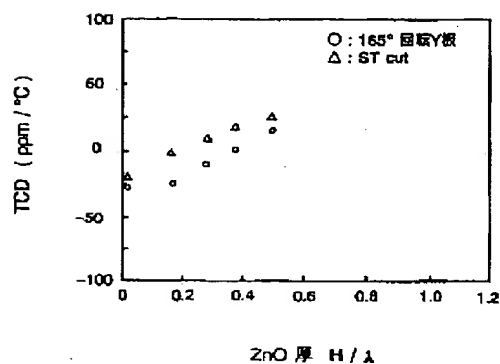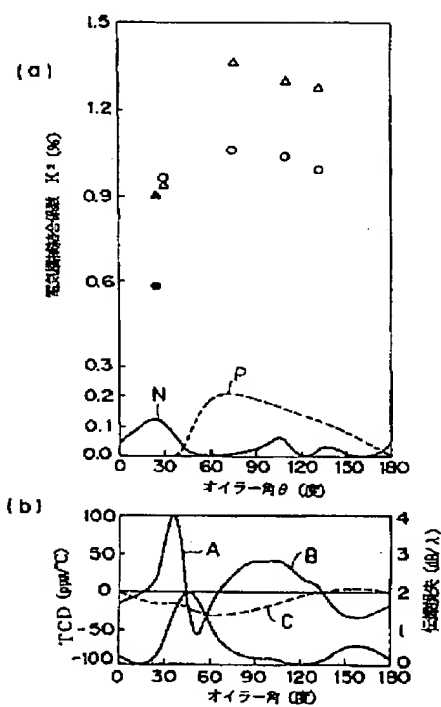
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Epitome

(57) [Abstract]
[Technical problem] an electromechanical coupling coefficient is larger
than before using the Xtal substrate -- SAW equipment offer is made.
[Means for Solution] SAW equipment which formed the ZnO thin film 12 on
the Xtal substrate 10, came to form the sinking comb electrodes 13a, 13b,
14a, and 14b on the ZnO thin film 12, and made standardization thickness
H/lambda of the ZnO thin film 12 0.05 or more.

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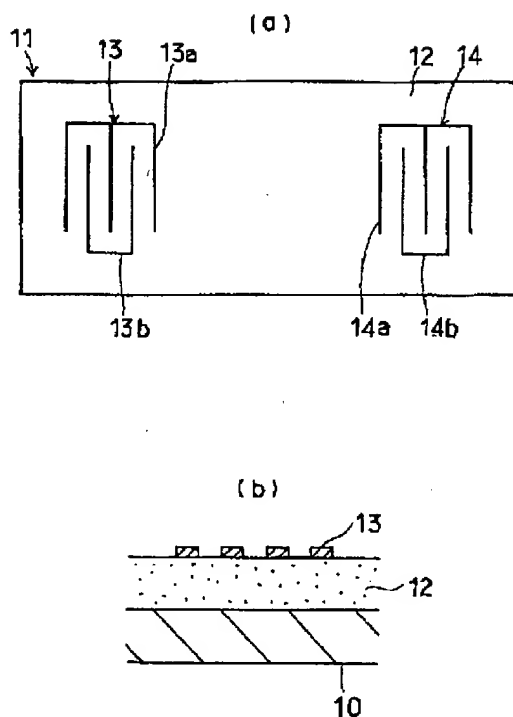
(a)

(b)

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CLAIMS

[Claim(s)]
[Claim 1] Surface wave equipment characterized by making standardization
thickness H/lambda of a piezo-electric thin film or more into 0.05 when
it forms on the Xtal substrate, the piezo-electric thin film formed on
said Xtal substrate, and said piezo-electric thin film, and it carried
out, and it has a gear-tooth electrode and wavelength of H and a surface

wave is set to lambda for the thickness of said piezo-electric thin film.
[Claim 2] Surface wave equipment according to claim 1 further equipped
with said Xtal substrate and the short circuit electrode formed between
said piezo-electric thin films.
[Claim 3] Surface wave equipment which forms and carries out, is
equipped with a gear-tooth electrode so that the Xtal substrate, the
piezo-electric thin film formed on said Xtal substrate, and said piezo-
electric thin film may be touched, and is characterized by using the
Xtal substrate of the cut angle in which the group delay temperature
characteristic TCD has the value of minus as said Xtal substrate, and
the propagation direction.
[Claim 4] Surface wave equipment according to claim 3 with which said
sinking comb electrode is formed on said piezo-electric thin film.
[Claim 5] Surface wave equipment according to claim 4 further equipped
with the short circuit electrode formed between said Xtal substrate and
said piezo-electric thin film.
[Claim 6] Surface wave equipment according to claim 3 to 5 whose
thickness H/lambda by which the piezo-electric thin film was
standardized is 0.03 or more when wavelength of H and a surface wave is
set to lambda for the thickness of said piezo-electric thin film.
[Claim 7] Said piezo-electric thin film is ZnO, AlN, and Ta 2O5. And
surface wave equipment according to claim 1 to 6 which is the piezo-
electric thin film which consists of a kind chosen from the group which
consists of CdS.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]

[Field of the Invention] This invention relates to amelioration of the surface wave equipment using the surface wave substrate which comes to carry out the laminating of the piezo-electric thin film on the Xtal substrate especially about the surface wave equipment which used the Xtal substrate.

[0002]

[Description of the Prior Art] Conventionally, surface wave equipment is widely used for the band-pass filter of for example, mobile communication equipment etc. Surface wave (following, SAW) equipment has the structure in which at least one INTADEJITARUTORANSUDEYUSA (following, IDT) which consists of sinking comb electrodes of a pair at least so that a piezo electric crystal may be touched was formed.

[0003] Moreover, various SAW equipments using a piezo-electric thin film are also proposed in recent years. That is, the SAW equipment using the surface wave substrate which comes to form a piezo-electric thin film on a glass substrate or a piezo-electric substrate is proposed.

[0004] Four kinds of structures shown in drawing 1 (a), (b), and drawing 2 (a) and (b) are known for the configuration using the above-mentioned piezo-electric thin film and a glass substrate. That is, with the SAW equipment 1 shown in drawing 1 (a), the ZnO thin film 3 is formed as a piezo-electric thin film on the glass substrate 2, and IDT4 is formed on the ZnO thin film 3. On the other hand, IDT4 is formed in the inferior surface of tongue of the ZnO thin film 3, i.e., the interface between a glass substrate 2 and the ZnO thin film 3, with the SAW equipment 5 shown in drawing 1 (b).

[0005] Moreover, with the SAW equipment 6 shown in drawing 2 (a), the short circuit electrode 7 is formed on the glass substrate 2, and the laminating of the ZnO thin film 3 is carried out on this short circuit electrode 7. IDT4 is formed on this ZnO thin film 3. That is, SAW equipment 6 is equivalent to the structure which inserted the short circuit electrode 7 in the interface of a glass substrate 2 and the ZnO thin film 3 in the SAW equipment 1 shown in drawing 1 (a).

[0006] With the SAW equipment 8 shown in drawing 2 (b), the short circuit electrode 7 is formed on the ZnO thin film 3. Moreover, IDT4 is formed in the interface between a glass substrate 2 and the ZnO thin film 3. Therefore, SAW equipment 8 is equivalent to the structure in which the above-mentioned short circuit electrode 7 was formed on the top face of the ZnO thin film 3, in the SAW equipment 5 shown in drawing 1 (b).

[0007] The electromechanical coupling coefficient at the time of changing the above-mentioned SAW equipments 1, 5, 6, and 8, and making

only the formation location of IDT4 and existence of the short circuit electrode 7 the same [other configurations] for them is shown in drawing 3 . Change of the electromechanical coupling coefficient to thickness H/lambda by which the ZnO thin film in the four above-mentioned kinds of SAW equipments 1, 5, 6, and 8 was standardized is shown by drawing 3 . In addition, in this specification, H shows the wavelength of the surface wave by which lambda is excited in the thickness of a ZnO thin film. Moreover, as a result of a continuous line's A being SAW equipment 1, an alternate long and short dash line C shows the result of SAW equipment 6, and a two-dot chain line D shows [a broken line B] the result of SAW equipment 8 for the result of SAW equipment 5.

[0008] By choosing H/lambda shows that a big electromechanical coupling coefficient is obtained compared with the SAW equipments 1 and 6 in the SAW equipments 5 and 8 so that clearly from drawing 3 . Therefore, with the structure in which the ZnO thin film 3 was formed on the glass substrate 2, it was supposed conventionally that an electromechanical coupling coefficient with bigger forming IDT4 in the interface between a glass substrate 2 and the ZnO thin film 3 will be obtained. In addition, the wave currently described as the SEZAWA wave in drawing 3 is a surface wave of the higher mode of a Rayleigh wave.

[0009] Moreover, in Jpn. J. Appl. Phys. Vol. 32 (1993) 2333-2336 page, it is LiNbO3. Change of the electromechanical coupling coefficient by IDT at the time of using the surface wave substrate which comes to constitute a ZnO thin film on a piezo-electric single crystal substrate, or the location of a short circuit electrode is shown. This is explained with reference to drawing 4 (a), (b), and drawing 5 (a) and (b).

[0010] Drawing 4 (a) is LiNbO3 about the glass substrate 2 in the SAW equipment 1 shown in drawing 1 (a). The relative thickness kh (k is 2 pi/lambda and h is the thickness of a ZnO thin film) and the electromechanical coupling coefficient K2 of the ZnO thin film about the SAW equipment of structure replaced with a piezo-electric single crystal substrate Relation is shown. In addition, continuous-line + is LiNbO3. About the case where a ZnO thin film is formed on a plus side, broken-line - is LiNbO3. It is a property at the time of forming a ZnO thin film in a minus side. Similarly, drawing 4 (b) is LiNbO3 about the glass substrate 2 of the SAW equipment 5 shown in drawing 1 (b). Electromechanical coupling coefficient K2 at the time of transposing to a piezo-electric single crystal substrate It is shown drawing and a continuous line is LiNbO3. When a ZnO thin film is formed on a plus side, a broken line shows the property at the time of forming a ZnO thin film

on a minus side. Furthermore, drawing 5 (a) is the electromechanical coupling coefficient K2 at the time of transposing the glass substrate 2 of the SAW equipment 8 with which drawing 5 (b) showed the glass substrate 2 of the SAW equipment 6 shown in drawing 2 (a) to drawing 2 (b) to a LiNbO3 piezo-electricity single crystal substrate, respectively. It is drawing showing change.

[0011] It is LiNbO3 so that clearly from drawing 4 and drawing 5 . Electromechanical coupling coefficient K2 with bigger forming IDT in the interface between a piezo-electric single crystal substrate and a ZnO thin film also in the structure which formed the ZnO thin film as a piezo-electric thin film on the piezo-electric single crystal substrate, so that clearly from drawing 4 (b) and drawing 5 (b) It turns out that it can realize.

[0012] that is, when using conventionally the surface wave substrate in which the ZnO thin film was formed on the glass substrate or the piezo-electric substrate, for obtaining a big electromechanical coupling coefficient, IDT should be formed between a piezo-electric thin film and a substrate -- ** -- it thought.

[0013] On the other hand, an electromechanical coupling coefficient is not only large, but depending on the application, the temperature characteristic is good, namely, the surface wave substrate with a small change of the property by the temperature change is called for, and Xtal is known as a substrate ingredient with the good temperature characteristic. However, the Xtal substrate had the problem that an electromechanical coupling coefficient was comparatively small.

[0014] As mentioned above, the Xtal substrate has the good temperature characteristic. For example, as shown in drawing 10 , it is known for the rotation Y cut Xtal substrate that there is relation like illustration between an Eulerian angle, and TCD and a propagation loss. Here, TCD shows the rate of change (a unit is ppm/**) by the temperature of a time delay.

[0015] In addition, in drawing 10 , in a continuous line A, a continuous line B shows a propagation loss and a broken line C shows TCD of the Rayleigh surface wave for TCD at the time of exciting a leakage surface acoustic wave on a rotation Y cut Xtal substrate. However, the propagation loss of a Rayleigh wave is zero.

[0016] Since TCD and the propagation-loss property which are shown in drawing 10 were known, the rotation Y cut Xtal substrate of nearly 130 degrees was conventionally used for the Eulerian angle shown in drawing 10 . That is, the SAW equipment with which the Xtal substrate of the cut angle of the zero neighborhood is used, and TCD comes to form IDT on

this Xtal substrate was used as good SAW equipment of the temperature characteristic.

[0017] However, also in the SAW equipment using the Xtal substrate constituted as mentioned above, too, when an SAW filter was constituted, it was difficult [it / the electromechanical coupling coefficient was small, therefore] to obtain the filter shape of a low insertion loss or a broadband.

[0018]

[Problem(s) to be Solved by the Invention] The purpose of this invention is in the SAW equipment using the surface wave substrate which comes to carry out the laminating of the Xtal substrate and the piezo-electric thin film to offer the thing equipped with the structure which can raise an electromechanical coupling coefficient further.

[0019] Moreover, other purposes of this invention are to offer SAW equipment with a much more big electromechanical coupling coefficient good [the temperature characteristic].

[0020]

[Means for Solving the Problem] This invention is made in order to attain the above-mentioned technical problem, and according to the large aspect of affairs of invention of the 1st of this application When it forms on the Xtal substrate, the piezo-electric thin film formed on said Xtal substrate, and said piezo-electric thin film, and it carried out, and it has a gear-tooth electrode and wavelength of H and a surface wave is set to lambda for the thickness of a piezo-electric thin film, the surface wave equipment characterized by making standardization thickness H/lambda of a piezo-electric thin film or more into 0.05 is offered.

[0021] With the surface wave equipment concerning invention of the 1st of this application, the piezo-electric thin film is formed on the Xtal substrate as mentioned above, and the sinking comb electrode is formed on this piezo-electric thin film. That is, when the surface wave substrate which comes to carry out the laminating of a non-piezo-electricity substrate or a piezo-electric substrate, and the piezo-electric thin film was used conventionally, it burned IDT, and the gear-tooth electrode should be formed between the substrate and the piezo-electric thin film, and the direction of it was considered that it can enlarge an electromechanical coupling coefficient. However, it came [the invention-in-this-application person came in the header and the pan that the direction which formed the piezo-electric thin film on the Xtal substrate, and formed the sinking comb electrode on the piezo-electric thin film could raise an electromechanical coupling coefficient in the case of the Xtal substrate which is a piezo-electric substrate,

and] to make [the above-mentioned specific thickness, then that an electromechanical coupling coefficient can be raised further] the piezo-electric thin film in that case for the 1st invention of a header and this application.

[0022] the above-mentioned surface wave equipment -- if it is, it has further preferably the short circuit electrode formed between the Xtal substrate and the piezo-electric thin film. According to the large aspect of affairs of invention of the 2nd of this application, it forms and carries out and has a gear-tooth electrode so that the Xtal substrate, the piezo-electric thin film formed on said Xtal substrate, and said piezo-electric thin film may be touched, and the surface wave equipment characterized by using the Xtal substrate of the cut angle in which the time delay temperature characteristic TCD has the value of minus as said Xtal substrate, and the propagation direction is offered.

[0023] In the 2nd invention, the Xtal substrate of the cut angle in which the time delay temperature characteristic TCD has the value of minus as a Xtal substrate, and the propagation direction is used, and the laminating of another side and the piezo-electric thin film is carried out on the Xtal substrate so that clearly from explanation of the below-mentioned operation gestalt. As for a piezo-electric thin film, the time delay temperature characteristic TCD usually has the value of plus. Therefore, with the above-mentioned surface wave equipment of this invention, since the time delay temperature characteristic TCD is offset with the Xtal substrate and a piezo-electric thin film, the good temperature characteristic is realized.

[0024] On the other hand, the Xtal substrate of the cut angle in which the time delay temperature characteristic TCD has the value of minus, and the propagation direction has a big electromechanical coupling coefficient compared with the Xtal substrate of a cut angle with the time delay temperature characteristic TCD near zero, and the propagation direction so that it may mention later. Therefore, according to the 2nd invention, the temperature characteristic can offer the surface wave equipment which has a bigger electromechanical coupling coefficient good.

[0025] According to another specific aspect of affairs of the 2nd invention, the above-mentioned sinking comb electrode is formed on a piezo-electric thin film, therefore can realize a much more big electromechanical coupling coefficient like the case of the 1st invention.

[0026] Furthermore, according to another specific aspect of affairs of the 2nd invention, it has further the short circuit electrode formed between the Xtal substrate and the piezo-electric thin film, and an

electromechanical coupling coefficient is raised by it.

[0027] Moreover, according to still more nearly another aspect of affairs of the 2nd invention, when it considers as the thickness H of a piezo-electric thin film, and the wavelength lambda of a surface wave, thickness H/lambda by which the piezo-electric thin film was standardized is made or more into 0.03, and an electromechanical coupling coefficient is further raised by it.

[0028] Moreover, by the 1st and 2nd invention of this application, the above-mentioned piezo-electric thin film is ZnO, AlN, and Ta 205. And it may be constituted by kind chosen from the group which consists of CdS. But other piezo-electric thin films may be used. In the piezo-electric thin film which consists of an ingredient mentioned above, the time delay temperature characteristic TCD has the value of plus. Therefore, by constituting a piezo-electric thin film from an above-mentioned ingredient, as mentioned above, the temperature characteristic can constitute good SAW equipment from invention of the 2nd of this application.

[0029] The SAW equipment concerning invention of the 1st and the 2nd of this application can be applied to various SAW devices, such as an SAW filter, a SAW resonator, and the SAW delay line.

[0030]

[Embodiment of the Invention] Hereafter, the technique which will be the requisite for this invention is first explained as examples 1 and 2 of reference, referring to a drawing.

[0031] the example 1 of reference -- three kinds of following SAW equipments were first produced using the direction propagation Xtal substrate of ST cut X which has a diameter xof 76.2mm0.5mm dimension.

[0032] SAW equipment 11 -- The ZnO thin film was formed on the above-mentioned Xtal substrate on the whole surface, on it, predetermined distance was separated, two IDT(s) were formed, and the SAW filter was produced. That is, as shown in drawing 9 (a), on the piezo-electric thin film 12, predetermined distance was separated and IDT 13 and 14 was formed. IDT 13 and 14 has the sinking comb electrodes 13a and 13b of a pair, and 14a and 14b, respectively. Moreover, with this SAW equipment 11, as shown in drawing 9 (b), the ZnO thin film 12 is formed on the above-mentioned Xtal substrate 10.

[0033] SAW equipment 12 -- It differed in SAW equipment 11, and if it removed having formed IDT between the Xtal substrate and the ZnO thin film, SAW equipment 2 as well as SAW equipment 1 was formed.

[0034] SAW equipment 13 -- In SAW equipment 11, the short circuit electrode which consists of aluminum all over an interface was formed

between the ZnO thin film and the Xtal substrate, and others presupposed that it is the same as that of SAW equipment 11.

[0035] In the above-mentioned SAW equipments 11-13, various thickness of a ZnO thin film was changed and the relation between the thickness of a ZnO thin film and an electromechanical coupling coefficient was measured. A result is shown in drawing 6 . In drawing 6 , a broken line D, a continuous line E, and an alternate long and short dash line F show the result of the SAW equipments 11, 12, and 13, respectively. In addition, the axis of abscissa of drawing 6 shows thickness H/lambda by which the ZnO thin film was standardized.

[0036] By adjusting the thickness of a ZnO thin film shows that the biggest electromechanical coupling coefficient is obtained in SAW equipment 13, next a big electromechanical coupling coefficient is obtained in SAW equipment 11, and an electromechanical coupling coefficient becomes small by forming a ZnO thin film with SAW equipment 12 at reverse so that clearly from drawing 6 . The result shown in drawing 6 namely, in the direction propagation Xtal substrate of ST cut X Compared with Xtal with which ZnO is not formed, if IDT is formed between the ZnO film and Xtal, an electromechanical coupling coefficient will become small. On the other hand, when IDT is formed on a ZnO thin film, by showing that a big electromechanical coupling coefficient is obtained and inserting a short circuit electrode in the interface between the Xtal substrate and a ZnO thin film further more preferably shows that a bigger electromechanical coupling coefficient is obtained.

[0037] The following SAW equipments 14-16 were produced using the Xtal substrate of the direction propagation of 165-degree rotation Y cut X of a diameter xof example of reference 276.2mm0.5mm dimension (an Eulerian angle 0 degree, 75 degrees, 0 degree).

[0038] SAW equipment 14 -- It constituted like the SAW equipment 11 of the example 1 of reference mentioned above if the substrate ingredient was used as the above-mentioned direction propagation Xtal substrate of rotation Y cut X and things were removed.

SAW equipment 15 -- If it removed having used the above-mentioned direction propagation Xtal substrate of rotation Y cut X as a Xtal substrate, it constituted like the SAW equipment 12 produced in the example 1 of reference.

[0039] SAW equipment 16 -- If it removed having used the above-mentioned direction propagation Xtal substrate of rotation Y cut X, SAW equipment 16 as well as the SAW equipment 13 produced in the example 1 of reference was constituted.

In the above-mentioned SAW equipments 14-16, various thickness of a ZnO

thin film was changed and the electromechanical coupling coefficient was measured. A result is shown in drawing 7 .

[0040] In drawing 7 , in a broken line G, a continuous line H shows the result of SAW equipment 15, and an alternate long and short dash line I shows the result of SAW equipment 16 for the property of SAW equipment 14. When the direction propagation Xtal substrate of rotation Y cut X is used so that clearly from drawing 7 , it turns out [of an electromechanical coupling coefficient with the big direction at the time of forming on a ZnO thin film] like the case of the example 1 of reference is acquired rather than forming IDT, i.e., a sinking comb electrode, between a ZnO thin film and the Xtal substrate. Moreover, if the property of an alternate long and short dash line I and a broken line G is compared, by forming a short circuit electrode between the Xtal substrate and a ZnO thin film further shows that a much more big electromechanical coupling coefficient is obtained so that clearly.

[0041] Even if it is the case where the Xtal substrate with which cut angles differ is used from the result of the examples 1 and 2 of reference mentioned above, in using the surface wave substrate which comes to form a ZnO thin film on the Xtal substrate, it turns out by forming a sinking comb electrode on a ZnO thin film that a big electromechanical coupling coefficient is obtained. It explains per [which can raise an electromechanical coupling coefficient further on the assumption that the above-mentioned examples 1 and 2 of reference] example of an experiment of this invention.

[0042] the example 1 of an experiment -- the Xtal substrate which consists of a 115-degree rotation Y cut which has a diameter xof 76.2mm0.5mm dimension first was used. The Xtal substrate of this cut angle is one of the substrate ingredients with which it is known that the biggest electromechanical coupling coefficient can be obtained in a leakage surface acoustic wave. Moreover, the propagation direction of a leakage surface acoustic wave is the direction of X.

[0043] The SAW equipments 17-19 using the following leakage surface acoustic wave were produced using the above-mentioned direction propagation Xtal substrate of 115-degree rotation Y cut X.

SAW equipment 17 -- If it removed having used the above-mentioned Xtal substrate, it constituted like SAW equipment 11.

[0044] SAW equipment 18 -- If it removed having used the above-mentioned Xtal substrate, SAW equipment 18 as well as SAW equipment 12 was produced.

SAW equipment 19 -- If it removed having used the above-mentioned specific Xtal substrate, SAW equipment 19 as well as SAW equipment 13

was produced.

[0045] Various thickness of the ZnO thin film of the above-mentioned SAW equipments 17-19 was changed, and the electromechanical coupling coefficient was measured. A result is shown in drawing 8 . In drawing 8 , as for a continuous line K, a broken line J shows [the result of SAW equipment 17] the experimental result about SAW equipment 19 for the result about SAW equipment 18, as for an alternate long and short dash line L.

[0046] Moreover, in the property shown in drawing 8 , distinction of the case where the excited surface wave is a leakage surface acoustic wave, and the case where it is the usual Rayleigh wave was shown in drawing 8 . That is, it turned out that the leakage surface acoustic wave accompanied by attenuation is excited, and the thickness by which the ZnO thin film was standardized cannot use it for SAW equipments, such as a transversal mold using propagation, less than [H/lambda =0.14] (location shown with a two-dot chain line M) so that clearly from drawing 8 . However, it may be able to be used for the SAW component which does not need propagation. Therefore, by making or more into 0.14 thickness by which the ZnO thin film was standardized shows that SAW equipment with the big electromechanical coupling coefficient by which attenuation is not accompanied is obtained.

[0047] Moreover, with the SAW equipment 18 in which the sinking comb electrode was formed between the Xtal substrate and the ZnO thin film, it turns out that a leakage surface acoustic wave cannot be excited effectively so that clearly from drawing 8 . On the other hand, with the SAW equipments 17 and 19 which come to form IDT, i.e., a sinking comb electrode, on a ZnO thin film, an electromechanical coupling coefficient is large and by making above-mentioned H/lambda or more into 0.14 shows that the SAW equipment using a leakage surface acoustic wave without attenuation can be offered. In the case of a leakage surface acoustic wave, as shown in drawing 10 B, there is attenuation of 0.2 dB/lambda by the 115-degree rotation Y cut X propagation which the propagation constants which show attenuation according to the cut angle of a substrate differed, and was shown here, but depending on a cut angle, there is a place (for example, X propagation of 105-degree rotation Y cut or 30-degree rotation Y cut) whose attenuation is zero. On such a cut square, attenuation does not follow in the place where ZnO thickness H/lambda is larger than 0.05, but a large electromechanical coupling coefficient is obtained.

[0048] In addition, it turns out that thickness H/lambda by which the ZnO thin film which can excite the cut angle of the Xtal radical to be

used and the surface wave to be used was standardized differs so that clearly, if the result shown in drawing 6 - drawing 8 is compared. Like the direction propagation Xtal substrate of ST cut X mentioned above, and the direction propagation Xtal substrate of 165-degree rotation Y cut X, in the case of a Rayleigh wave surface wave H/lambda -- 0.05 or more [then] and a good thing -- further -- the case of a leakage surface acoustic wave -- a 115-degree rotation Y cut X propagation Xtal substrate -- H/lambda -- 0.14 or more and a 105-degree rotation Y cut X propagation Xtal substrate -- H/lambda -- 0.05 or more -- then, it is good. Therefore, when forming a ZnO thin film on the Xtal substrate, as for thickness H/lambda by which the ZnO thin film was standardized, carrying out to 0.05 or more is desirable.

[0049] As mentioned above, since various rotation Y cuts from which an Eulerian angle differs were used as a used Xtal substrate, class creation of much above-mentioned SAW equipments using the Xtal substrate with which Eulerian angles differ was carried out. Thus, the above-mentioned Eulerian angle and electromechanical coupling coefficient K2 of SAW equipment which were obtained O mark is attached and relation is shown in drawing 16 (a).

[0050] In addition, as for the broken line P of a leakage surface wave, the continuous line N of drawing 16 (a) shows the electric machine engagement multiplier of the Xtal substrate of the rotation Y cut X propagation in the case of a Rayleigh wave itself. the square of the electromechanical coupling coefficient of the Rayleigh wave in the structure which O mark in drawing and - mark formed the ZnO film on Xtal, respectively, and formed IDT on it further, and a leakage surface acoustic wave -- value K2 It is shown. the square of the electromechanical coupling coefficient of a Rayleigh wave when ** mark and ** mark prepare a short circuit electrode in the boundary of ZnO and Xtal further on the other hand at the structure, respectively, and a leakage surface acoustic wave -- value K2 It is shown. Thus, K2 With cut angles, it changes somewhat. Moreover, drawing 16 (b) is again illustrated directly under drawing 16 (a) for the comparison with drawing 16 (a), although it is the same Fig. as drawing 10 .

[0051] Although TCD used the Xtal substrate which has the neighboring cut angle of zero in order to improve the temperature characteristic when the SAW equipment using the Xtal substrate was constituted conventionally as explained with reference to example of experiment 2 drawing 10 , a sufficiently big electromechanical coupling coefficient was not able to be obtained in this case. The invention-in-this-application person found out that good TCD and a big electromechanical

coupling coefficient could be obtained, when combining the Xtal substrate whose TCD is minus, and the ZnO thin film in the relation between the Eulerian angle shown in drawing 10 , and TCD.

[0052] In addition, in the field of minus of TCD, the relation between the cut angle of the Xtal substrate and the propagation direction, and TCD exists also in which Xtal substrate. This is explained with reference to drawing 11 - drawing 14 .

[0053] Drawing 11 shows relation with the include angles theta and TCD from the X-axis of the propagation direction in ST cut Xtal substrate, in drawing 12 , drawing 13 shows relation with the include angles theta and TCD from the X-axis of the propagation direction of Y cut Xtal substrate, and drawing 14 shows relation with the include angles theta and TCD from the X-axis of the propagation direction of Z cut Xtal substrate for relation with the include angles theta and TCD from the Y-axis of the propagation direction of an X-cut-crystal substrate. Also in these Xtal substrates, that the field where TCD is subtracted exists changes by changing the propagation vectorial angle theta so that clearly from drawing 11 - drawing 14 .

[0054] Invention of the 2nd of this application realizes good TCD and a big electromechanical coupling coefficient, when the above TCD(s) combine the piezo-electric thin film in which the value of TCD's plus of the Xtal substrate of the cut angle which shows the value of minus, or the propagation direction is shown. The Xtal substrate which consists this of a rotation Y cut is taken for an example, and it explains with reference to drawing 15 .

[0055] First, the substrate of a diameter xof 76.2mm0.5mm dimension was prepared as a Xtal substrate. In addition, as this Xtal substrate, two kinds, 165-degree rotation Y cut X propagation and ST cut 35 degree propagation, were prepared.

[0056] The ZnO film was formed by the thickness to H/lambda =0-0.5 on the above-mentioned Xtal substrate, and IDT was formed so that it might be further in agreement in the above-mentioned propagation direction on it. The SAW measured the temperature characteristic (temperature 15, three 25 or 35-degree C points) of the time delay of a property. The result is shown in drawing 15 . By 165-degree rotation Y cut X propagation, it turns out by ST cut 35 degree propagation that it becomes TCD=0 about ZnO thickness H/lambda =0.16 about H/lambda =0.35. Moreover, the electromechanical coupling coefficient in this thickness shows a large value as mentioned above. That is, in 165-degree rotation Y cut X propagation, they are the former and an electromechanical coupling coefficient K2. When what was TCD=-30ppm/degree C formed the

ZnO film and IDT of H/lambda =0.35 in the Xtal substrate 0.2%, 5 times
[over the past] as many K2 =1.04% as this and TCD=0ppm/degree C were
obtained. Moreover, by preparing a short circuit electrode between the
ZnO film and the Xtal substrate, it becomes TCD=0ppm/degree C and is K2.
1.35 still larger% is obtained.

[0057] On the other hand, it is K2 when the former and that they were K2
=0.14% and TCD=-20ppm/degree C form the ZnO film and IDT of H/lambda
=0.16 on the Xtal substrate also in ST cut 35 degree propagation. 4.8
times as many K2 =0.77% as this and TCD=0ppm/degree C are obtained.
Moreover, if a short circuit electrode is prepared between the ZnO film
and the Xtal substrate, K2 =0.89% and TCD=0ppm/degree C will be obtained
further.

[0058] Therefore, though TCD has the value of minus in that case as a
Xtal substrate using the Xtal substrate of an Eulerian angle with a big
electromechanical coupling coefficient so that clearly from this example
of an experiment By forming the ZnO thin film in which TCD of the plus
which may offset the value of minus of TCD of the Xtal substrate as a
ZnO thin film is shown, and forming IDT on it shows that the SAW
equipment which has a very big electromechanical coupling coefficient
and the good temperature characteristic can be constituted.

[0059] Although the above-mentioned explanation explained two kinds of
substrates, when a rotation Y cut and the Xtal substrate of other cut
angles shown in drawing 11 - drawing 14 are used, even if TCD is minus,
by using the Xtal substrate of an Eulerian angle with a big
electromechanical coupling coefficient shows similarly that surface wave
[with a large and electromechanical coupling coefficient] equipment
with the good temperature characteristic can be constituted. That is, as
shown in drawing 10 , in the Rayleigh wave in rotation Y cut X
propagation, it is the range of minus [Eulerian angle (0, 0, 0) - (0,
20, 0), - (0, 45, 0) (0 65, 0) - (0, 135, 0) (0 180, 0) the range] of
TCD in an Eulerian angle (0, 0, 0) - (0, 135, 0) range, and leakage
surface wave. the case where ST cut Xtal substrate is used as shown in
drawing 11 -- from an Eulerian angle (5 0,132. 75**0) -- (-- between
0,132. 75**5 and 50) -- and (0,132. 75**5,130) -- from -- TCD is in the
range of minus between (0,132.75**5,180).

[0060] Moreover, in the rotation X-cut-crystal substrate, TCD is [the
Eulerian angle] subtracted between the range of - (90, 90, 0) (90, 90,
35), and (90 90,145) - (90 90,180) so that clearly from drawing 12 .

[0061] Similarly, in the rotation Y cut Xtal substrate, TCD is [the
Eulerian angle] subtracted between (0, 90, 0), and (0, 90, 35) and (0
90,145) between - (0 90,180) as shown in drawing 13 . Moreover, with Z

cut Xtal substrate, when phi of an Eulerian angle (0, 0, phi) is the
propagation directions other than 0, 60,120, and 180, the value of TCD
is the value of minus, so that clearly from drawing 14 .
[0062] Therefore, surface wave [with a large and electromechanical
coupling coefficient] equipment with the good temperature
characteristic can be constituted like the above by forming in the top
face of each Xtal substrate the ZnO thin film which has the TCD value of
plus, and forming IDT further so that the large cut angle of an
electromechanical coupling coefficient may be chosen also in the range
in the range mentioned above although each Xtal substrate shows the
value of minus of TCD, and the value of minus of TCD may be offset.
[0063] Moreover, when the ingredient of a single crystal like the Xtal
substrate is used, the direction of the phase-velocity vector which goes
to IDT from IDT, and the propagation direction of actual energy may stop
being in agreement with the anisotropy of that cut angle, this
phenomenon is called power flow, and the include angle produced at this
time is called power flow angle. When this power flow is taken into
consideration, a power flow angle is 0 and the cut angle of the Xtal
substrate [as / whose angle as TCD indicates the value of minus to be
to coincidence is 0] is desirable. This desirable cut angle An Eulerian
angle (0, 25, 0) - (0, 105, 0) between, Between - (0, 45, 35) - (0, 10,
60) (0, 20, 70) between, (0, 0, 15) Between - (0, 180, 45) - (0, 0, 85)
(0, 0, 90) between, (0, 90, 30) (90, 90, 25) It is between - (90, 90,
31) - (0, 90, -3) (0, 90, 3) in between, and TCD is minus in this case,
and a power flow angle is 0.
[0064] Therefore, by forming a ZnO thin film on each Xtal substrate in
the range mentioned above, and forming IDT further, the temperature
characteristic is greatly good and an electromechanical coupling
coefficient can constitute the surface wave equipment which does not
have a bias in the propagation direction.
[0065] In addition, although the above-mentioned example of an
experiment explained the case where a ZnO thin film was formed as a
piezo-electric thin film, the proper piezo-electric thin film which has
the TCD value of pluses, such as AlN and Ta 205 besides a ZnO thin film,
and CdS, may be used.
[0066] Furthermore, about the Xtal substrate, it points out that any of
a plus side and a minus side may be used.
[0067]
[Effect of the Invention] As mentioned above, in invention of the 1st of
this application, the sinking comb electrode is formed on the piezo-
electric thin film formed on the Xtal substrate, and since

standardization thickness H/lambda of a piezo-electric thin film is made
or more into 0.05, the surface wave equipment with which a big
electromechanical coupling coefficient is obtained can be offered. That
is, it becomes possible to raise an electromechanical coupling
coefficient by leaps and bounds compared with the structure in which the
sinking comb electrode was formed, between the Xtal substrates and the
piezo-electric thin films which were presupposed that a big
electromechanical coupling coefficient can be obtained conventionally.
[0068] Moreover, according to invention of the 2nd of this application,
the Xtal substrate of the cut angle in which TCD has the value of minus
as a Xtal substrate, and the propagation direction is used, and the
piezo-electric thin film is formed on this Xtal substrate. Therefore,
since a piezo-electric thin film has the TCD value of usually plus, the
TCD value of the Xtal substrate is offset by the TCD value of a piezo-
electric thin film, and the good surface wave equipment of the
temperature characteristic can be obtained. Therefore, even if a TCD
value is minus, by using the Xtal substrate of the large cut angle of an
electromechanical coupling coefficient, and the propagation direction,
the temperature characteristic which was not able to be realized
conventionally is good and it becomes possible to offer the surface wave
equipment which has an electromechanical coupling coefficient big
moreover.

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] (a) And (b) is each sectional view showing the glass
substrate in conventional surface wave equipment, a piezo-electric thin
film, and the laminated structure of IDT, respectively.

[Drawing 2] (a) And (b) is each sectional view for explaining the glass substrate in conventional SAW equipment, a short circuit electrode, a piezo-electric thin film, and the laminated structure of IDT, respectively.

[Drawing 3] Thickness by which the piezo-electric thin film in the SAW equipment shown in drawing 1 and drawing 2 was standardized, and drawing showing relation with an electromechanical coupling coefficient.

[Drawing 4] (a) And set to conventional SAW equipment and (b) is LiNbO3, respectively. Structure and LiNbO3 in which a piezo-electric thin film and IDT were formed on the substrate Drawing showing the relation of the thickness and the electromechanical coupling coefficient in the structure which carried out the laminating of IDT and the piezo-electric thin film to this order on the substrate by which the ZnO thin film was standardized.

[Drawing 5] (a) And (b) is LiNbO3, respectively. Drawing showing the relation of the thickness and the electromechanical coupling coefficient by which the ZnO thin film at the time of forming in a location which is different in IDT and a short circuit electrode in the surface wave substrate which comes to form a ZnO thin film on a substrate was standardized.

[Drawing 6] Drawing showing the relation of the thickness and the electromechanical coupling coefficient by which the ZnO thin film of three kinds of surface wave equipments in which the piezo-electric thin film and the sinking comb electrode were formed on ST cut Xtal substrate was standardized.

[Drawing 7] Drawing showing the relation of the thickness and the electromechanical coupling coefficient by which the ZnO thin film of the surface wave equipment of three kinds of structures in which the ZnO thin film and the sinking comb electrode were formed on the direction propagation Xtal substrate of 165-degree rotation Y cut X was standardized.

[Drawing 8] Drawing showing the relation of the thickness and the electromechanical coupling coefficient by which the ZnO thin film in the surface wave equipment which constituted the ZnO thin film and the sinking comb electrode in various gestalten on the Xtal substrate which consists of a 115-degree rotation Y cut was standardized.

[Drawing 9] (a) And (b) is a partial notching sectional view of a part in which the typical top view and sinking comb electrode of SAW equipment which are constituted as the example of reference and 1 operation gestalt of this invention are formed.

[Drawing 10] Drawing showing relation with the Eulerian angle, TCD, and

the propagation loss in a rotation Y cut Xtal substrate.
[Drawing 11] Drawing showing the relation of the propagation direction
and TCD in ST cut Xtal substrate.
[Drawing 12] Drawing showing the relation between the propagation
direction of an X-cut-crystal substrate, and TCD.
[Drawing 13] Drawing showing the relation between the propagation
direction of Y cut Xtal substrate, and TCD.
[Drawing 14] Drawing showing the relation between the propagation
direction of Z cut Xtal substrate, and TCD.
[Drawing 15] Drawing showing the relation between the ZnO thickness at
the time of using 165-degree rotation Y cut X propagation and an ST cut
35 degree propagation Xtal substrate, and TCD.
[Drawing 16] (a) And (b) is drawing showing the relation of the Eulerian
angle of a rotation Y cut Xtal substrate and electromechanical coupling
coefficient in the operation gestalt of invention of the 2nd of this
application, and drawing showing the relation between an Eulerian angle,
TCD, and a propagation loss in a list, respectively.
[Description of Notations]
10 -- Xtal substrate 11
 -- SAW equipment
12 -- ZnO thin film
13 14 -- IDT
13a, 13b, 14a, 14b -- Sinking comb electrode

[Translation done.]

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3. In the drawings, any words are not translated.

DRAWINGS

[Drawing 1]

(a)

[Drawing 2]

(a)

(b)
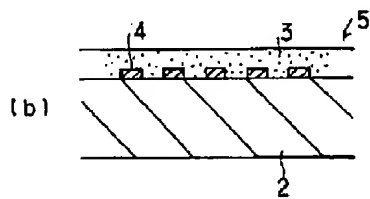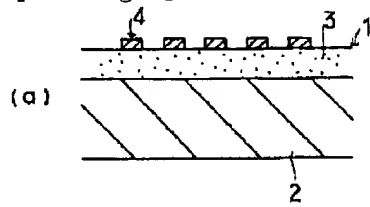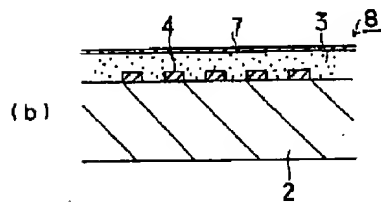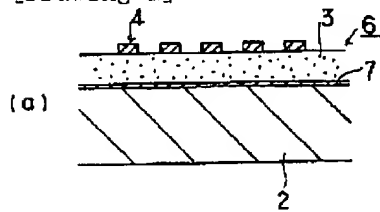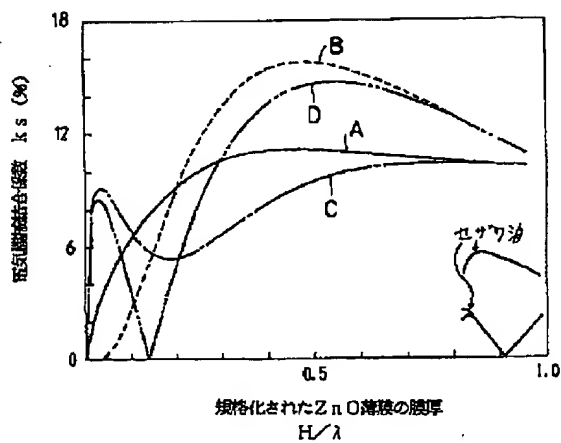
[Drawing 3]

[Drawing 4]

(a)
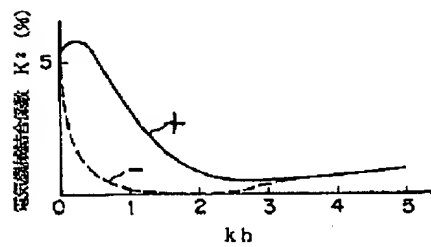
(b)
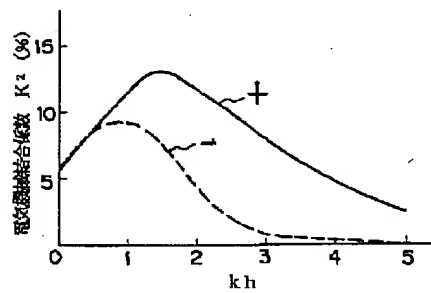
[Drawing 6]
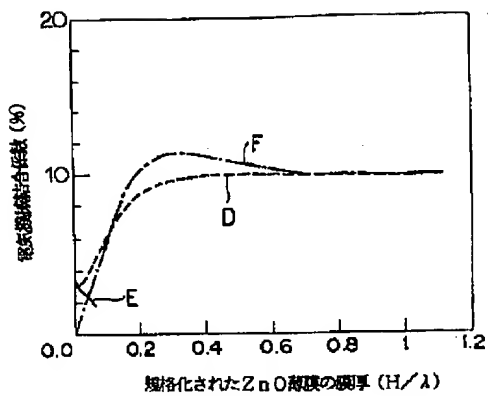
[Drawing 5]

(a)
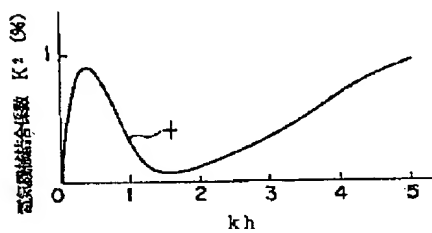
(b)
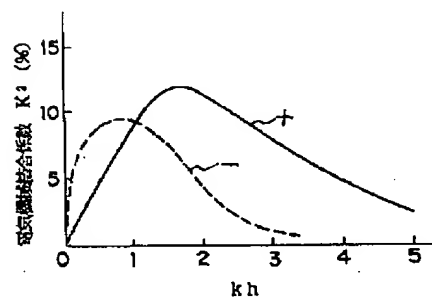
[Drawing 7]
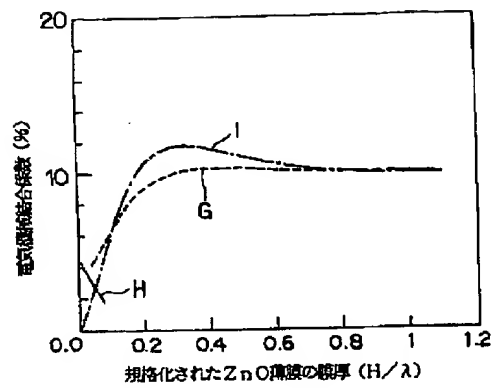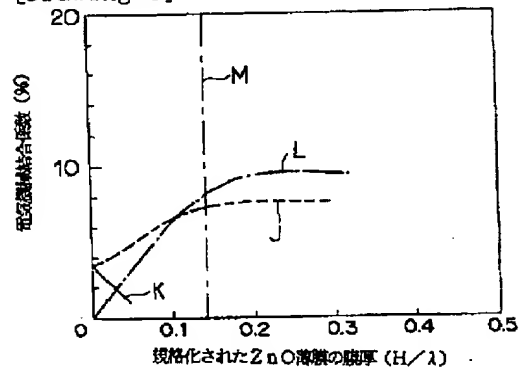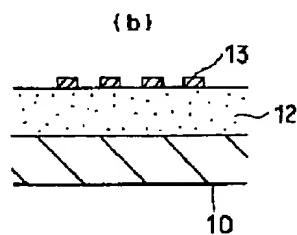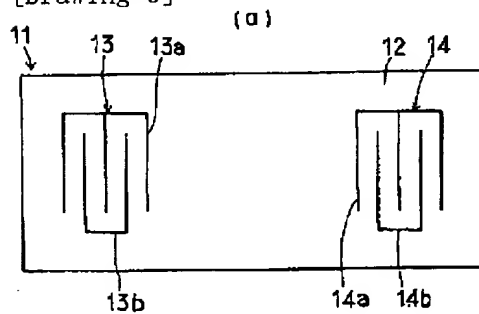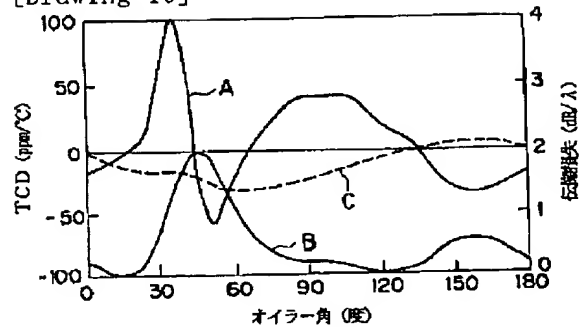
[Drawing 8]

[Drawing 9]

(a)

(b)

[Drawing 10]

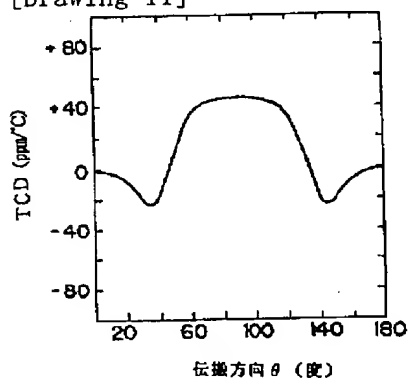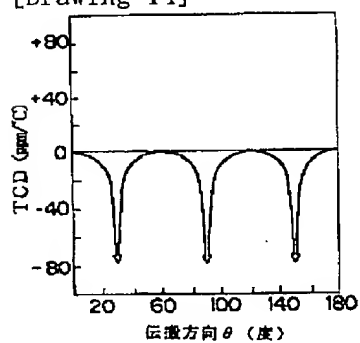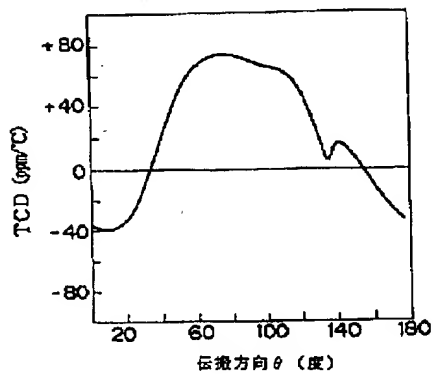[Drawing 11]
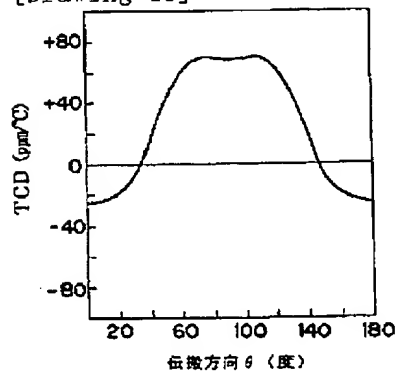

[Drawing 14]

[Drawing 12]

[Drawing 13]

[Drawing 15]

[Drawing 16]

(a)

電気機械結合係数 K² (%)

N

P

オイラー角θ (度)

(b)

TCD (ppm/℃)

A

B

C

伝搬損失 (dB/λ)

オイラー角 (度)

[Translation done.]